

Imaging magnetic nanostructures with soft X-ray microscopy at the XM-1

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INTRODUCTION

The occurrence of magnetic domains on a sub-micrometer length scale is intimately related with fundamental ferromagnetic parameters like exchange and anisotropy constants. Magnetic systems with reduced dimensions as e.g. multilayered or laterally nanostructured thin films are furthermore of outstanding technological relevance in current developments like magneto-optics, GMR based sensor systems or future devices in MRAM technology. To study both the fundamental physics of ferromagnetism and to understand the functionality of real magnetic devices imaging techniques should provide both high lateral resolution on a nanometer scale, a large magnetic contrast connected with high sensitivity, a chemical selectivity and the capability to work in varying applied fields. The combination of the imaging capabilities of a transmission X-ray microscope (TXM) and the X-ray magnetic circular dichroism (X-MCD) as huge magnetic contrast mechanism meets those requirements as has been demonstrated for the first time recently at the TXM at BESSY I [1]. X-ray magnetic circular dichroism, i.e. the variation of the X-ray absorption coefficient for circularly polarized photons in ferromagnetic media yields magnetic contributions to the absorption cross section in the case of 3d transition metals up to 50% with photon energies close to element-specific absorption edges. The dichroic contrast probes the component of the local magnetization onto the photon propagation direction and the application of magneto-optical sum-rules to magnetic absorption profiles at spin-orbit coupled absorption edges (e.g. $L_{2,3}$) allows to determine separately spin and orbital moments quantitatively with high relative accuracy.

RESULTS

At the XM-1 [2,3] circularly polarized X-rays are obtained by viewing the off-orbit contribution emitted from the bending magnet. Magneto-optical recording layers consisting of 50nm thin $Tb_{25}(Fe_{75}Co_{25})_{75}$ films were sputtered with different ratios of Rare Earth to Transition Metal content thus tailoring the coercive field of the systems. Both packed and isolated bit patterns of various sizes were written both with laser pumped magnetic field modulation (LP-MFM) and light intensity modulation (LIM). After the thermomagnetic recording, the films were peeled off from the substrate to allow for the limited penetration depth of soft X-rays. The M-TXM images were taken at the Fe L_3 edge at a photon energy of 706eV where the largest magnetic contrast is to be expected. One of the issues that should be addressed was, how reliable the smallest bits can be written according to the thermodynamics involved in the writing process.

As our results show, with LP-MFM the smallest isolated domains could be seen down to 30nm, which is consistent with the design values estimated from the writing parameters, but could also been proven by analyzing the data within a power spectrum. The influence of an additional topping Al layer, which acts as a heat sink could also been demonstrated. The temperature profile is steeper and as a result the domain edges are more clearly shaped [4-7].

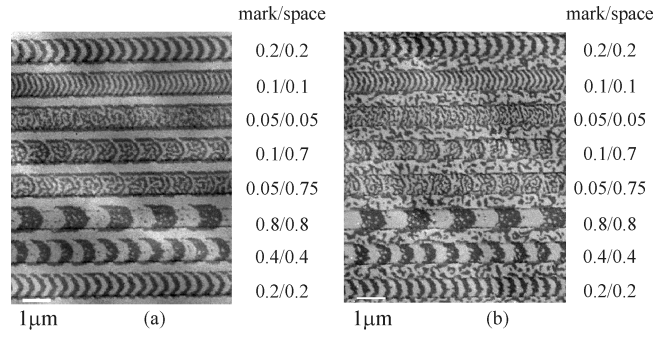


Fig 1: M-TXM images taken at the Fe L_3 edge in a SiN(70nm) / Tb₂₅(Fe₇₅Co₂₅)₇₅ (50nm) / SiN(20nm) / Al(30nm) / SiN(20nm) (a) and SiN(70nm) / Tb₂₅(Fe₇₅Co₂₅)₇₅ (50nm) / SiN(20nm) (b) MO media. The mark/space assignments are given in μm .

An inherent feature of the M-TXM is the element-selectivity, which allows to address a single element in a multicomponent system. Thus information on the chemical morphology, which influences drastically the behaviour of the global magnetization in the presence of external fields can be obtained. Thus M-TXM images had been recorded at the Fe $L_{3,2}$ and the Co L_3 edge. The observed change in contrast between the L_3 and the L_2 edge originates in the opposite spin-orbit coupling in the respective $2p_{3/2}$ and $2p_{1/2}$ inneratomic levels. The fact that even at the Co L_3 edge the domain pattern is clearly visible points to the sensitivity of M-TXM down to a few nanometer thin samples.

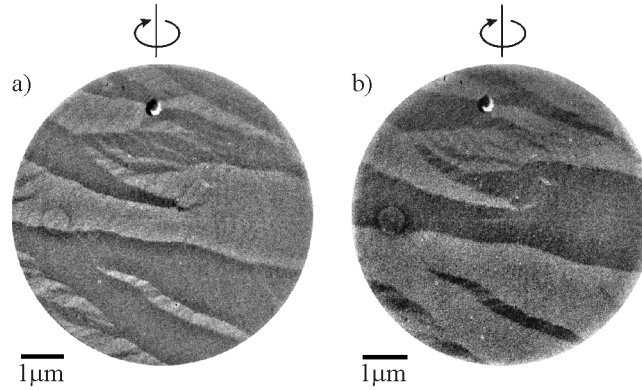


Fig 2 M-TXM images of a Cr (3nm) / Fe (50nm) / Cr (6nm) system taken at the Fe L_3 (a) and L_2 (b) absorption edge. The tilt axis is indicated

Extending the M-TXM to image in-plane magnetized domains is of high interest, as this is the most favorable configurations for magnetic systems of low dimensionality. Thus a sample stage to tilt the sample up to 30° relative to the photon propagation direction was inserted into the XM-1. As a trial system thin (36-50nm) thermally evaporated Fe samples were prepared onto $3 \times 3 \text{ mm}^2$ large and 100nm thin Si_3N_4 membranes to reduce the absorption of background photons in the substrate. The images of the Cr (3nm) / Fe (50nm) / Cr (6nm) system taken at the Fe L_3 (706eV) and L_2 (719eV) absorption edges are shown in Fig. 2(a,b) [8]. The sample was mounted under a 30° tilt at an axis perpendicular to the photon propagation direction., therefore the projection of the Fe magnetization points in/out of the paper plane. The observed change in contrast, between the Fe L_3 and L_2 edge, resp., is an unambiguous proof of the magnetic character of the patterns observed. Furthermore, the technique presented here allows to distinguish within its lateral resolution between in-plane and out-of-plane contributions. The domain pattern shown in Fig. 2 has been observed in a virgin state, i.e. no magnetic field has been applied. As can be

seen from Fig.2 the domain patterns exhibit a variety of features like the typical ripple structure known from in-plane magnetization.

OUTLOOK

The XM-1 has proven to be suited for imaging magnetic domains with 25nm resolution. Both in-plane and out-of-plane systems can be addressed and as a photon based microscopy magnetic fields can be applied during recording. The huge contrast allows for imaging domains even in few nanometer thin samples. Together with the element-specificity the next steps will be to study the switching behaviour of individual layers in technologically relevant magnetic systems, like spin-valves, tunnel junctions, MRAMs, etc.

ACKNOWLEDGMENTS

We like to thank M. Köhler (U Regensburg) and M. Kumazawa (U Nagoya) for the preparation of samples.

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This work was supported by the German Science Foundation, the Volkswagen foundation and the Center for X-ray optics, Berkeley, CA.

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